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14. ABSTRACT
Automated validation methods and a suite of tools have been developed in a Quality Control Center to analyze the stability and uncertainty of satellite ocean products. The automatic procedures analyze match-ups of near real time coastal bio-optical observations from Martha's Vineyard Coastal Observatory (MVCO) with satellite-derived ocean color products from MODIS Aqua and Terra, SeaWIFS, Ocean Color Monitor, and MERIS. These tools will be used to compare MVCO in situ data sets (absorption, backscattering, and attenuation coefficients), co-located SeaPRISM-derived water leaving radiances, and the Aerosol Robotic Network (AeroNet) derived aerosol properties with daily satellite bio-optical products and atmospheric correction parameters (aerosol model types, epsilon, angstrom coefficient), to track the long term stability of the bio-optical products and aerosol patterns. The automated procedures will be used to compare the in situ and satellite-derived values, assess seasonal trends, estimate uncertainty of coastal products, and determine the influence and uncertainty of the atmospheric correction procedures. Additionally we will examine the increased resolution of 250m, 500m, and 1 km satellite data from multiple satellite borne sensors to examine the spatial variability and how this variability affects assessing the product uncertainty of coastal match-ups of both bio-optical algorithms and atmospheric correction methods. This report describes the status of the QCC tool development and potential applications of the QCC tool suite.

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Automated Validation of Satellite Derived Coastal Optical Products

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Automated validation methods and a suite of tools have been developed in a Quality Control Center to analyze the stability and uncertainty of satellite ocean products. The automatic procedures analyze match-ups of near real time coastal bio-optical observations from Martha's Vineyard Coastal Observatory (MVCO) with satellite-derived ocean color products from MODIS Aqua and Terra, SeaWIFS, Ocean Color Monitor, and MERIS. These tools will be used to compare MVCO in situ data sets (absorption, backscattering, and attenuation coefficients), co-located SeaPRISM-derived water leaving radiances, and the Aerosol Robotic Network (AeroNet) derived aerosol properties with daily satellite bio-optical products and atmospheric correction parameters (aerosol model types, epsilon, angstrom coefficient), to track the long term stability of the bio-optical products and aerosol patterns. The automated procedures will be used to compare the in situ and satellite-derived values, assess seasonal trends, estimate uncertainty of coastal products, and determine the influence and uncertainty of the atmospheric correction procedures. Additionally we will examine the increased resolution of 250m, 500m, and 1 km satellite data from multiple satellite borne sensors to examine the spatial variability and how this variability affects assessing the product uncertainty of coastal match-ups of both bio-optical algorithms and atmospheric correction methods. This report describes the status of the QCC tool development and potential applications of the QCC tool suite.

INTRODUCTION

In-water optical properties such as absorption and backscattering of in-water constituents and chlorophyll concentration can be derived from water leaving radiance measurements[1-5]. Water leaving radiances can be estimated from sub-surface measurements and above water measurements including ship, buoy, tower, aircraft and satellite borne measurements. Satellite observations of ocean conditions are an important tool used for many applications including climate change monitoring, coastal water quality (harmful algal blooms), and in-water optical property estimates for military operations support. Depending on orbit configurations, satellite measurements can give global coverage. Measurements conducted from aircraft, ships, towers or buoys cover much smaller spatial scales than satellites can provide. However, it is difficult to derive in-water products from satellite observations due to the fact that water leaving radiance is typically less than 10% of the radiance measured at the top of atmosphere. The atmospheric portion of the top of atmosphere radiance measurement must be removed before in-water optical property algorithms based on normalized water leaving radiances (nLw's) can be applied. Atmospheric correction algorithms work reasonably well for open ocean locations where water turbidity is low. Atmospheric correction algorithms currently used by the ocean color community assume that there is little or no radiance leaving the water in the near infrared. The water leaving radiance in the infrared is then either be estimated in an iterative method, or set to zero for very clear water. The atmospheric correction algorithms estimate the aerosol radiance in the infrared, and using 12 aerosol spectral models, extrapolate the infrared aerosol radiance into the visible portion of the radiance spectrum. This extrapolation is performed by the epsilon. However, coastal regions with high suspended sediment loading can have significant water leaving radiance in the infrared. This makes estimating the infrared water leaving radiance more difficult, and therefore makes selecting the correct aerosol radiance level and spectral model used to atmospherically correct the visible channels more difficult. These atmosphere errors in coastal waters are propagated into negative radiance and / or errors in the bio-optical properties.

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In addition to the difficulties in atmospheric correction in the coastal zone, many optical property algorithms fail in the optically complex coastal waters. A suite of tools has been developed which constitute a Quality Control Center. The QCC tools described here will be used to understand the root causes of the errors in satellite derived in-water optical properties estimates.

METHODS

A SQL database has been design in MySQL to contain the data measured at the Martha's Vineyard Coastal Observatory (MVCO). There are two types of data acquired from MVCO, in-water and above water measurements. The in water measurements are preformed manually and are less frequent than the above water measurements. The in-water measurements include absorption and scattering coefficients, and chlorophyll concentration. The above water measurements are automated robotic measurements using a water viewing spectra-radiometer and sky viewing sun photometer[6,7]. Water leaving radiances and aerosol optical thickness (AOT) estimates can be derived from measurements from these instruments. The water leaving radiances derived from the SeaPrism instrument can be directly compared to the satellite derived water leaving radiance. MVCO AOT are not directly compared to the satellite derived AOT values because the viewing geometry is not the same between the sun photometer and the satellite borne sensor. However, the spectral shape of the AOT can be compared between the 2 systems to give a comparison of the measured and modeled aerosol spectral shape.

The MVCO site is a platform where above water Rrs, and in-water bio-optical properties are collected. This data provides invaluable capabilities for determining the stability of ocean color products. Data from MVCO is downloaded daily and automatically screened for new data, which is ingested into the SQL database. The data ingest tool can be set to overwrite data in the database if necessary. For example, if a new calibration has been applied to the MVCO data, the new version of the data can be ingested into a new database, or it can be configured to replace the existing data.

A suite of software tools have been developed that are used to automatically process satellite data from multiple platforms referred to as the automated processing system (APS)[8]. The software uses an extension of the NASA SeaDAS MSl12 program which is capable of using multiple algorithms to process top of atmosphere radiance into in-water properties such as absorption due to phytoplankton, dissolved organic matter, and detritus, as well as backscattering coefficients, chlorophyll concentration, diver visibility and laser performance. The system produces products in user defined regions which are defined by a latitude and longitude box. Any satellite data that falls within the pre-defined region will automatically be processed by APS. A subset of the approximately 100 products produced by APS can be selected to be generated for each region. In addition to single pass images, APS can produce single day composites from multiple satellite passes or latest pixel composites from many days of derived products.

APS processes data through many levels which are defined as follows. Top of atmosphere, un-calibrated data is called Level 0 data. Data that has been converted from digital counts to calibrated top of atmosphere radiance values is considered Level 1a and geo-located Level 1a data is Level 1b data. Level 1b data is converted to Level 2 products through atmospheric correction and application of in-water property algorithms. Level 3 products are created from Level 2 products by mapping the Level 2 products into a pre-defined region of interest using a standard mapping projection. Level 4 products are composites of Level 3 products. For the study described here, satellite data used for match-ups comes from the Level 2 products. The use of Level 2 products for match-ups avoids the spatial mapping of Level 3 products and temporal averaging of the Level 4 data.

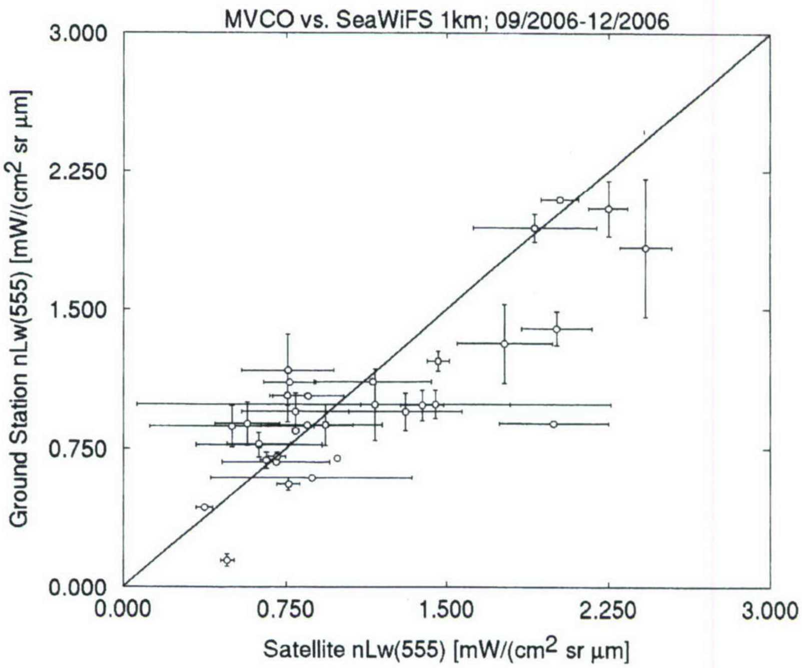
Additionally, a tool has been created that runs automatically as part of the APS system to extract data from every image that is processed by APS which covers a pre-defined calibration/validation site. The tool extracts the closest pixel to the latitude and longitude of the defined ground station or stations. The data extraction tool can also be configured to extract the pixels surrounding the closest pixel using a user defined pixel diameter. For example, if the user specifies a diameter of 3, a 3x3 pixel box, centered on the closest pixel to the ground station is stored in the SQL database setup for satellite data extractions. The SQL database is designed to store satellite derived products from multiple in-water optical property algorithms, derived water leaving radiances, aerosol optical thickness, and aerosol model types used to model the aerosol spectral shape applied during the atmospheric correction of each pixel. The great circle distance between the

ground station and each pixel is also stored. The distance parameter can be used to exclude data from match-ups that is too far away from the ground station. This is especially import in coastal regions where water mass properties can change substantially over very short distances, which can lead to misleading match-up results.

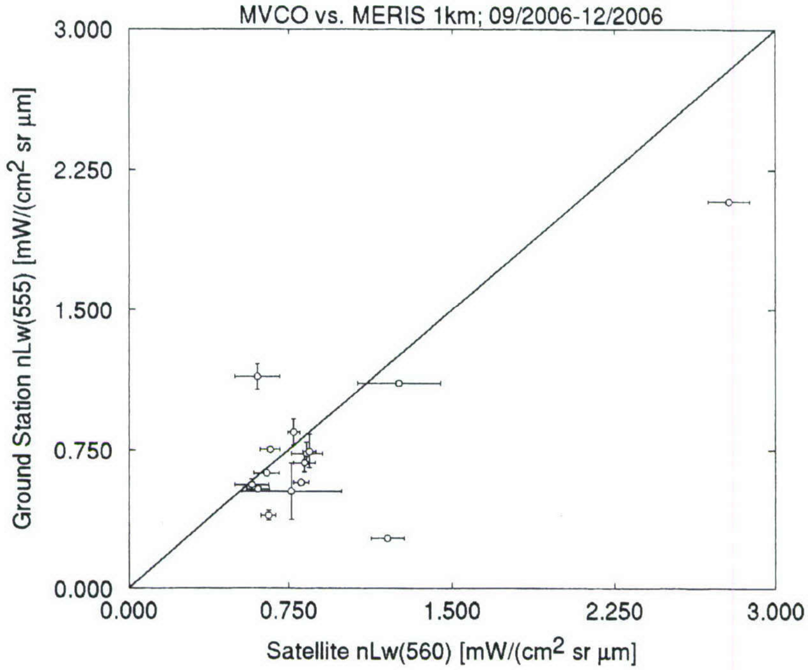
The Quality Control Center data analysis tool suite used to analyze match-up data is web based which allows users to interact with the tools from any operating system with a web browser. The software tools are implemented in PHP with a graphical package called jpGraph. These tools can be updated to include drop down menus that can drive scripts, or special plotting functions. Currently, we have setup standard plots to show scatter plots of nLw's, derived absorption and scattering coefficients as well as chlorophyll concentration. Examples of nLw match-ups and aerosol spectral shapes are shown below.

RESULTS

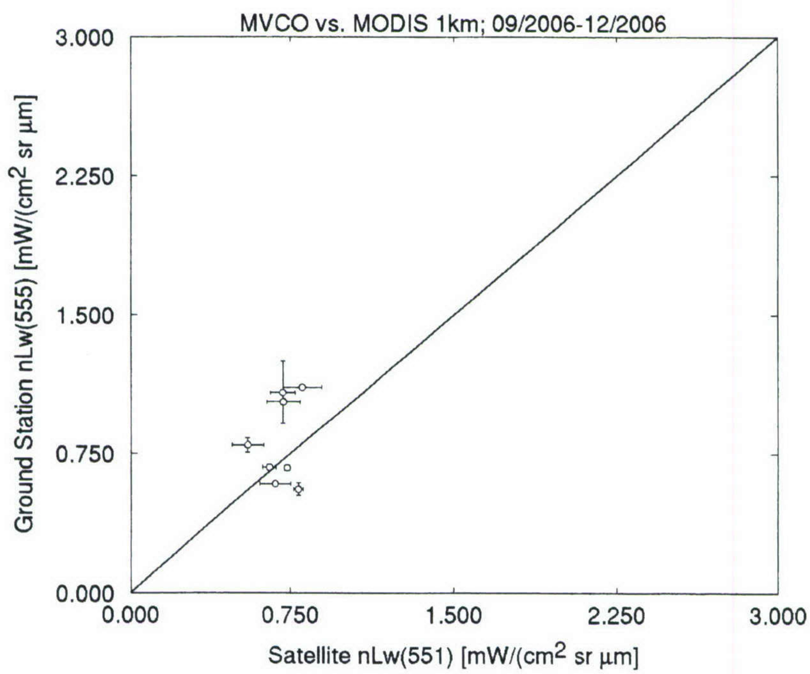
Atmospheric correction process is difficult to accomplish, especially in the coastal zone. In order to derive the best possible optical products from satellite derived radiances, the atmospheric correction process must work well or it propagates into uncertainty in the derived bio-optical products. Match-ups of normalized water leaving radiances give an indication of how well the atmospheric correction process is performing. Below are some examples of water leaving radiance match-ups from multiple satellites.



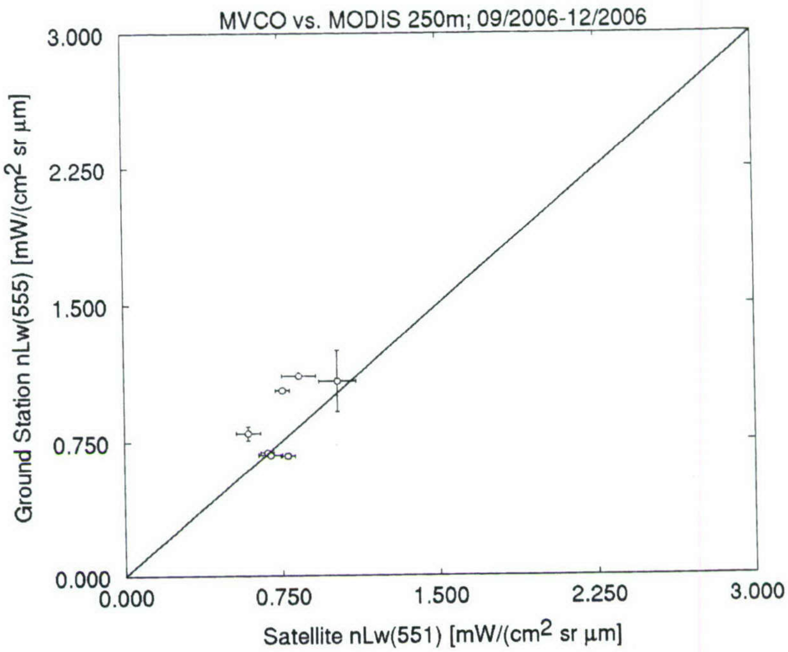
(a)


MVCO vs. MERIS 1km; 09/2006-12/2006
3.000
2.250
1.500
0.750
0.000
Ground Station nLw(555) [mW/(cm2 sr μm]
0.000
0.750
1.500
2.250
3.000
Satellite nLw(560) [mW/(cm2 sr μm]

(b)


MVCO vs. MODIS 1km; 09/2006-12/2006
3.000
2.250
1.500
0.750
0.000
Ground Station nLw(555) [mW/(cm2 sr μm]
0.000
0.750
1.500
2.250
3.000
Satellite nLw(551) [mW/(cm2 sr μm]

(c)



(d)

Figure 1 shows match-ups of normalized water leaving radiance (nLw) from the Martha's Vineyard Coastal Observatory (MVCO) SeaPrism instrument and (a) SeaWiFS 1km, (b) MERIS 1km, (c) MODIS 1km and (d) MODIS 250m spatial resolution nLw's. Vertical error bars represent the standard deviation of all valid data that was within +/- 2 hours of the satellite over pass. Horizontal error bars represent the standard deviation of all valid pixels within a 3x3 pixel box centered on the closest pixel to the MVCO tower.

Figure 1 shows the Quality Control Center test match-ups between the SeaPrism measured nLw(555nm) verses nLw(555nm) or nearest band) derived from SeaWiFS 1km spatial resolution data (Figure 1a), MERIS 1km spatial resolution data (Figure 1b), MODIS 1km spatial resolution data (Figure 1c) and MODIS 250m spatial resolution data (Figure 1d). The data points representing the satellite data were derived from an average of all valid pixels that fall within the 3x3 pixel grid centered on the closest pixel to the ground station location. The horizontal error bars represent the standard deviation of all valid pixels included in the average value. The data points representing the ground station data were derived from an average of all valid measurements that fall within +/- 2 hours of the satellite overpass. The vertical error bars represent the standard deviation of all valid measurements used to derive the average measurement value. There were many more match-up data points available from SeaWiFS in the database for the time frame used in the test area than the other sensors. This was due to the set of data files available at the time of the Quality Control Center system test.

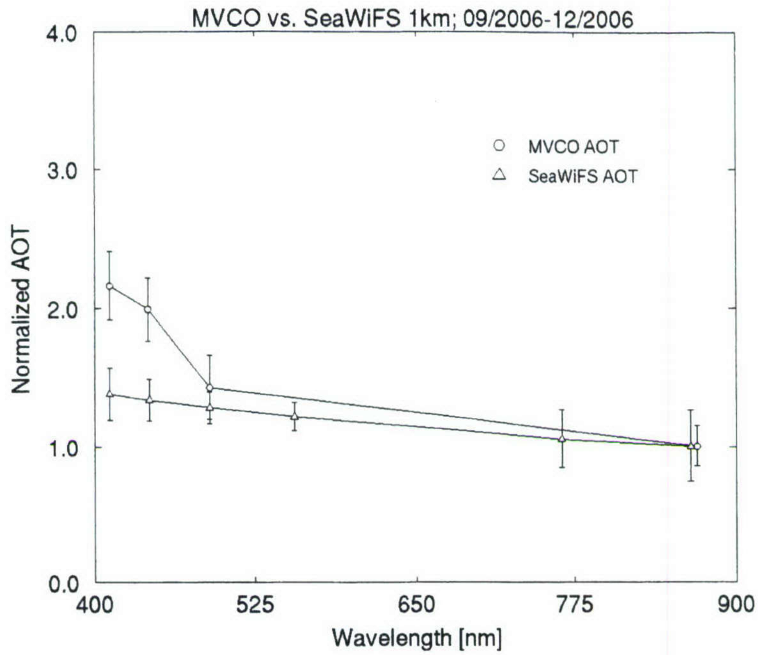


Figure 2 is an example of aerosol radiance spectral shape derived from normalized aerosol optical thickness (AOT) measurements from the Aeronet sun-photometer at MVCO and compared to SeaWiFS aerosol radiance spectral shape derived from aerosol optical thickness derived from the aerosol spectral model used during atmospheric correction of the satellite data. This is an example of where there was significant variation between the aerosol spectral shapes derived from the ground based and satellite estimates of the aerosol spectral shape.

Figure 2 and Figure 3 show examples of comparisons of normalized AOT from MVCO Aeronet data and SeaWiFS normalized AOT derived from the aerosol models used in the atmospheric correction. The AOT values are normalized to the 865nm channel which allows one to compare how the atmospheric correction algorithm extrapolated near infrared aerosol radiance into the visible portion of the spectrum. Again, the error bars on the MVCO data represent the standard deviation of all AOT values that fell within +/- 2 hours of the satellite over pass, and the error bars on the SeaWiFS data represents the standard deviation of all AOT values within the 3x3 pixel box surrounding the closest pixel to the MVCO tower. Figure 2 is an example where the spectral shape of aerosol radiance used during the atmospheric correction of the SeaWiFS data differs significantly from the aerosol spectral shape determined by the MVCO normalized AOT. This mismatch may have had an impact on the nLw's derived from the SeaWiFS data (not shown).

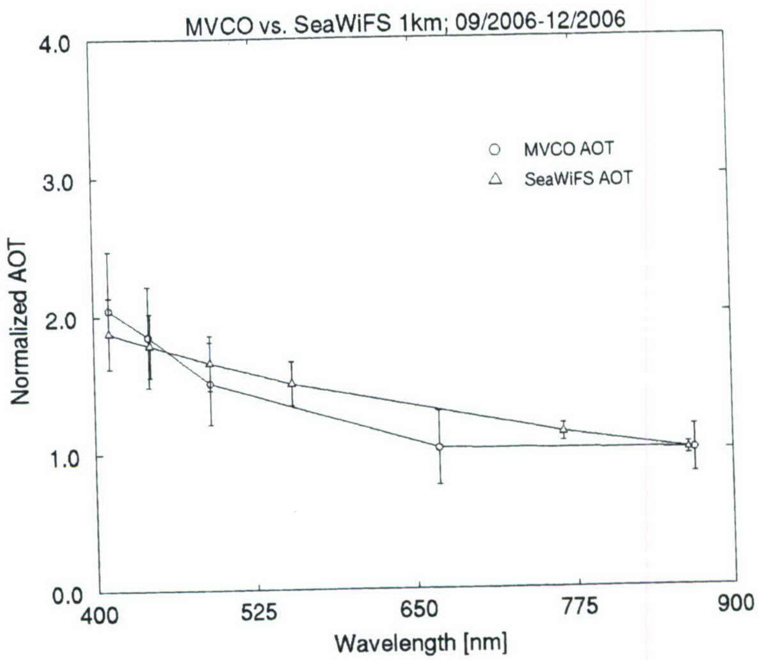


Figure 3 is an example of aerosol radiance spectral shape derived from normalized aerosol optical thickness (AOT) measurements from the Aeronet sun-photometer at MVCO and compared to SeaWiFS aerosol radiance spectral shape derived from aerosol optical thickness derived from the aerosol spectral model used during atmospheric correction of the satellite data. This is an example of where there was good agreement between the aerosol spectral shapes derived from the ground based and satellite estimates of the aerosol spectral shape.

Figure 3 is an example where the aerosol spectral shapes had better agreement between the MVCO data and the SeaWiFS data. In the QCC there will be an ability to click on an nLw match-up data point and a normalized AOT comparison plot such as Figure 2 and Figure 3 will be automatically generated in a pop-up window. These types of plots can be used to help understand if errors seen in the nLw match-ups are due to the atmospheric correction process or are caused by some other process.

DISCUSSION

Manually extracting data values from satellite data files that are coincident spatially and temporally with ground based measurements can be tedious and time consuming. This is especially true when in-water optical properties from multiple algorithms derived from multiple satellites borne sensors are compared to ground based measurements. Automating the steps used to create match-ups is an important feature of the suite of tools that constitute the QCC that is being created at the Naval Research Laboratory. The QCC tool suite will also allow for the analysis of derived optical properties. For match-ups where optical properties show large deviations, the aerosol spectral shapes used to atmospherically correct the satellite data and the resulting nLw's can be compared to ground based measurements to understand the impact of the atmospheric process on the derived optical properties. In addition, systematic biases within a particular sensor can be discovered by comparing nLw's scatter plots and temporal plots automatically created by the QCC tool suite.

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